




POWER CIRCLE

Electricity for sustainable energy

NASA Inspired Future Energy System

**NASA/ESA 2015 International Workshop on
Environment and Alternative Energy**

**Bo Normark
Royal Academy of Engineering Sciences**



Electricity for sustainable energy

Agenda

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- **NASA triggering energy transition**
- **Historic energy transitions**
- **Key technologies going forward**
 - Electrification
 - Efficiency
 - PV Solar, Wind
- **Enabling technologies**
- **Centralized or decentralized**
- **Summary**

Christer Fuglesang

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S116E05923

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One of the most famous images of the twentieth century, this view of the fully lit globe of Earth was taken from Apollo 17 shortly after its launch on December 7, 1972

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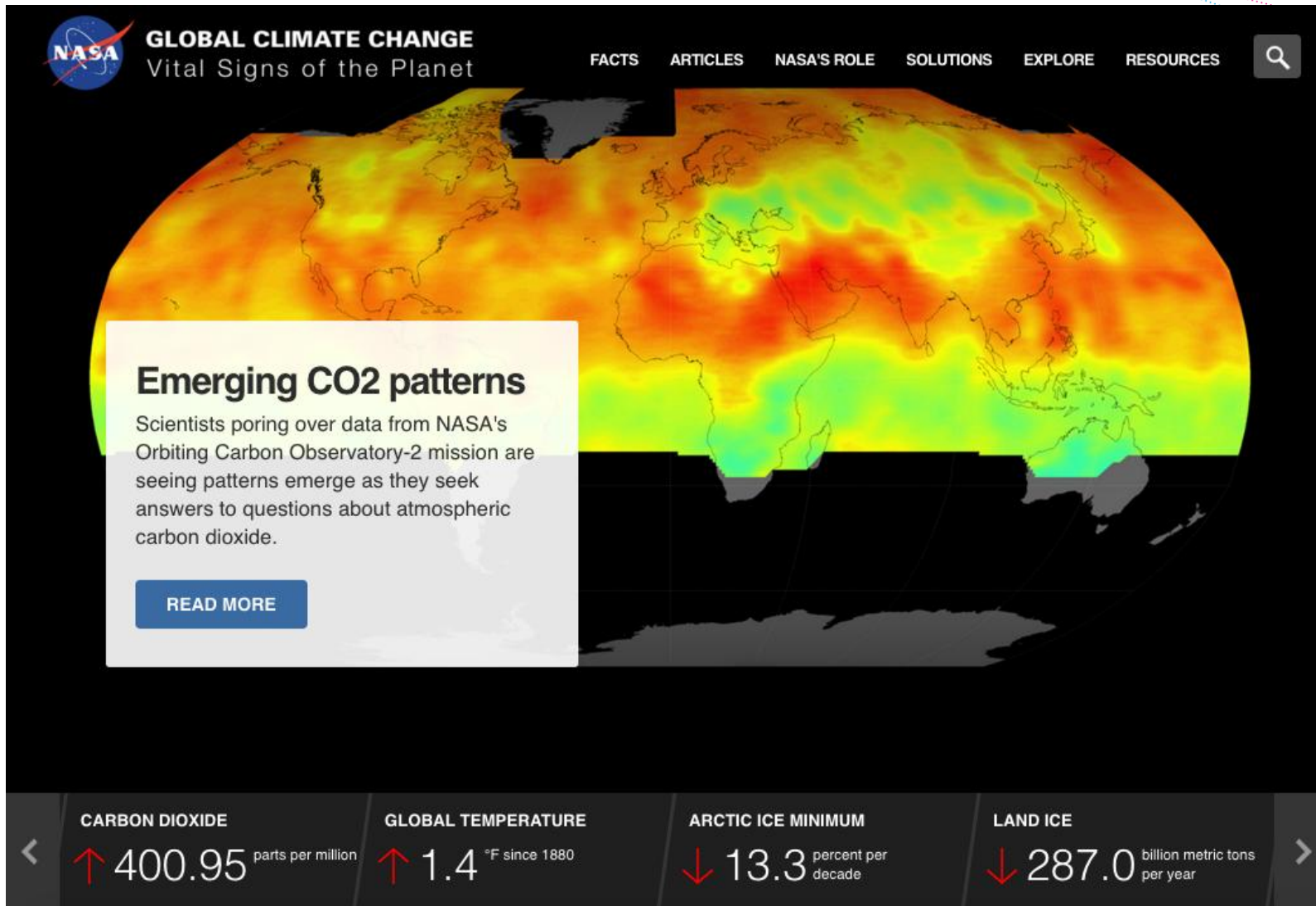


Electricity for sustainable energy

Illustrating the problem

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Illustrating the problem

Kilimanjaro Tanzania

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February 17, 1993



February 21, 2000

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Historic energy transitions

The role of technology



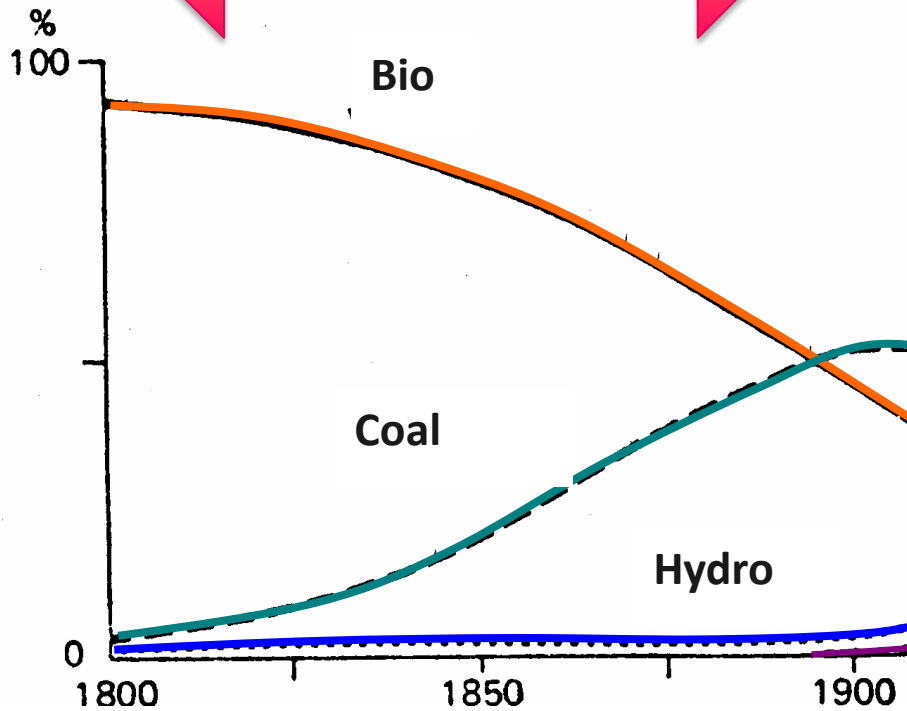
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Energy transitions Sweden

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Bio to Coal



Source: Energikommisionen, SOU 1978:17;
Energiläget 2004, Energimyndigheten

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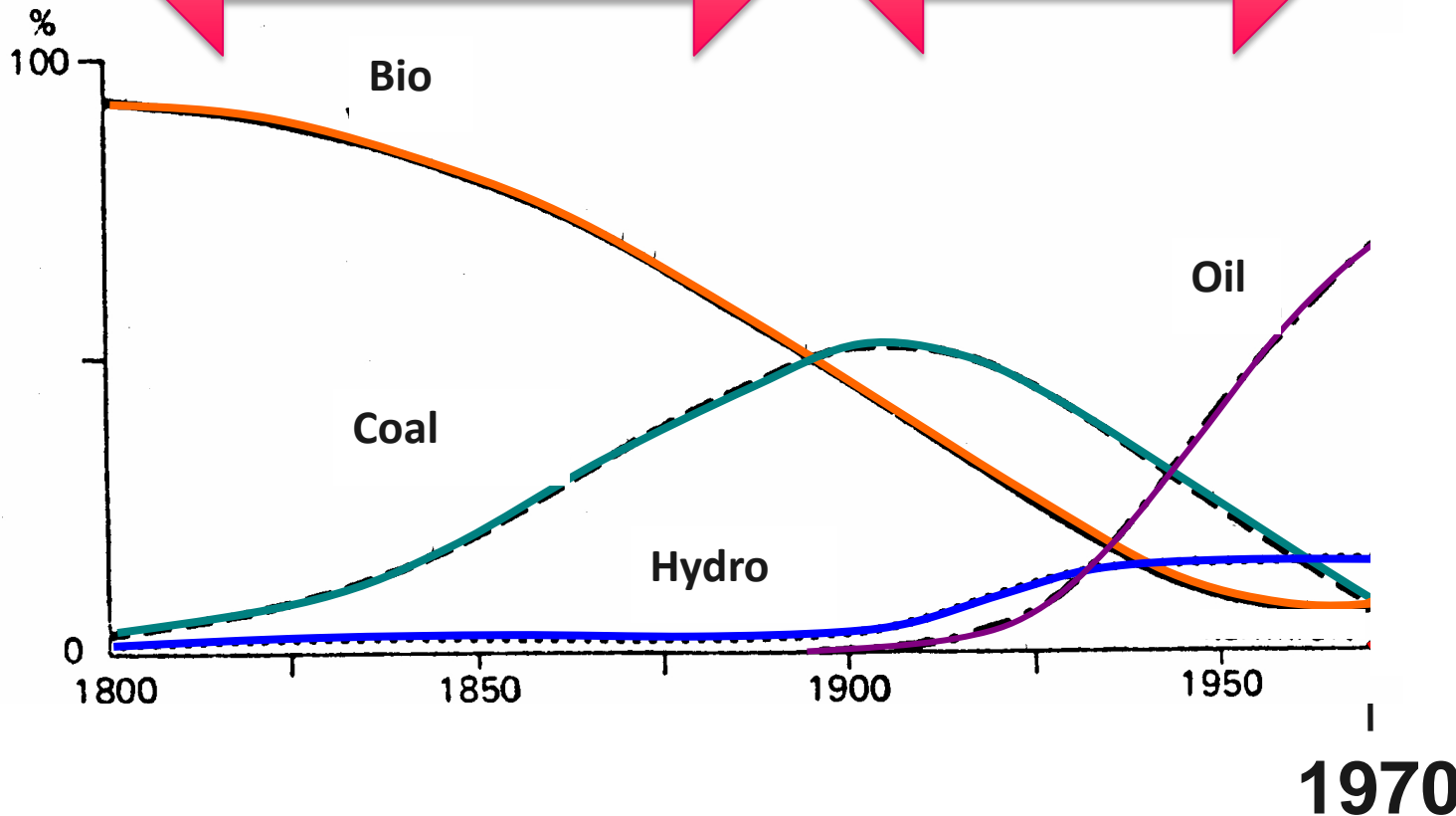
Energy transitions Sweden

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Bio to Coal

Coal to Hydro & Oil



Source: Energikommisionen, SOU 1978:17;
Energiläget 2004, Energimyndigheten

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Energy transitions Sweden

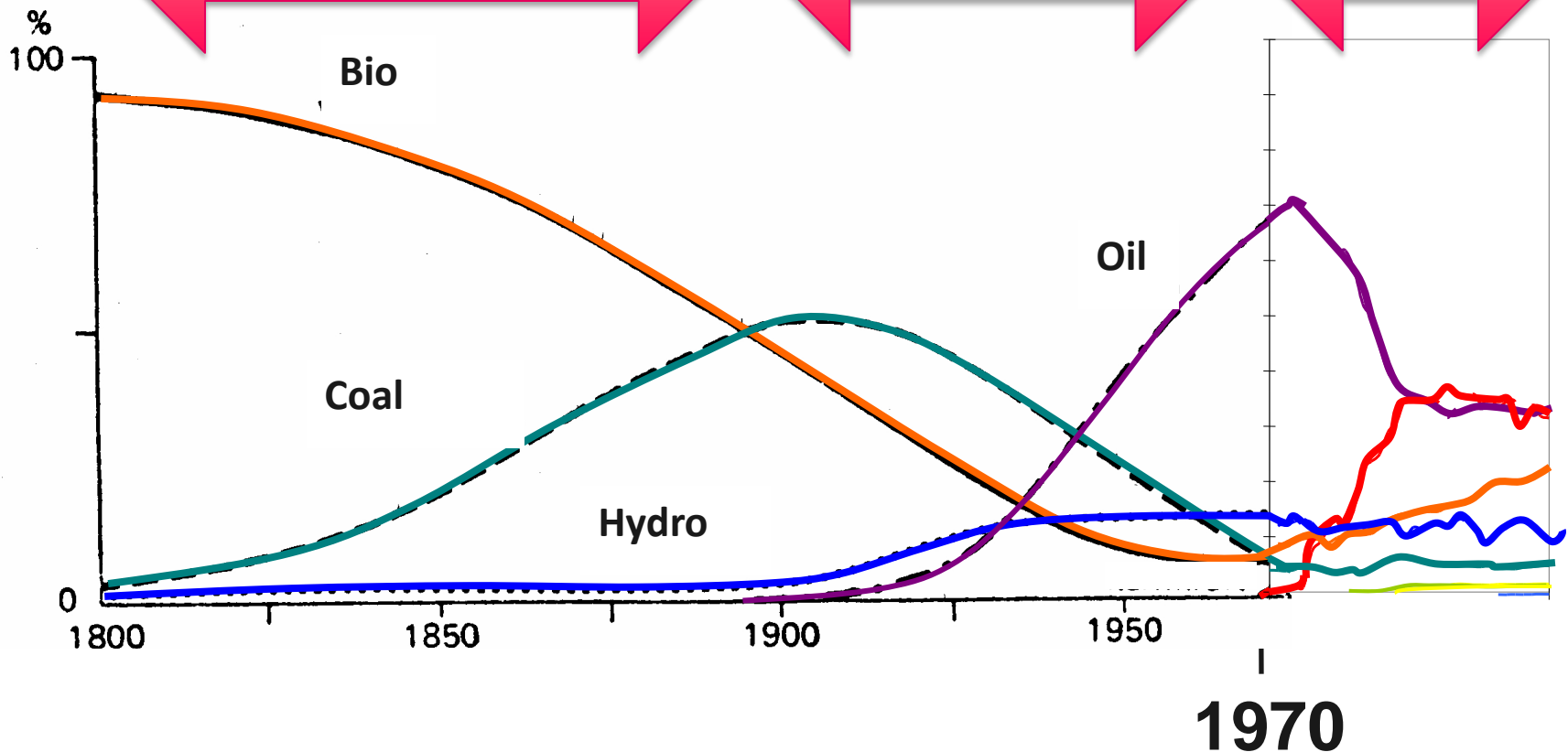
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Bio to Coal

Coal to Hydro & Oil

Oil to Bio
& Nuclear



Source: Energikommisionen, SOU 1978:17;
Energiläget 2004, Energimyndigheten

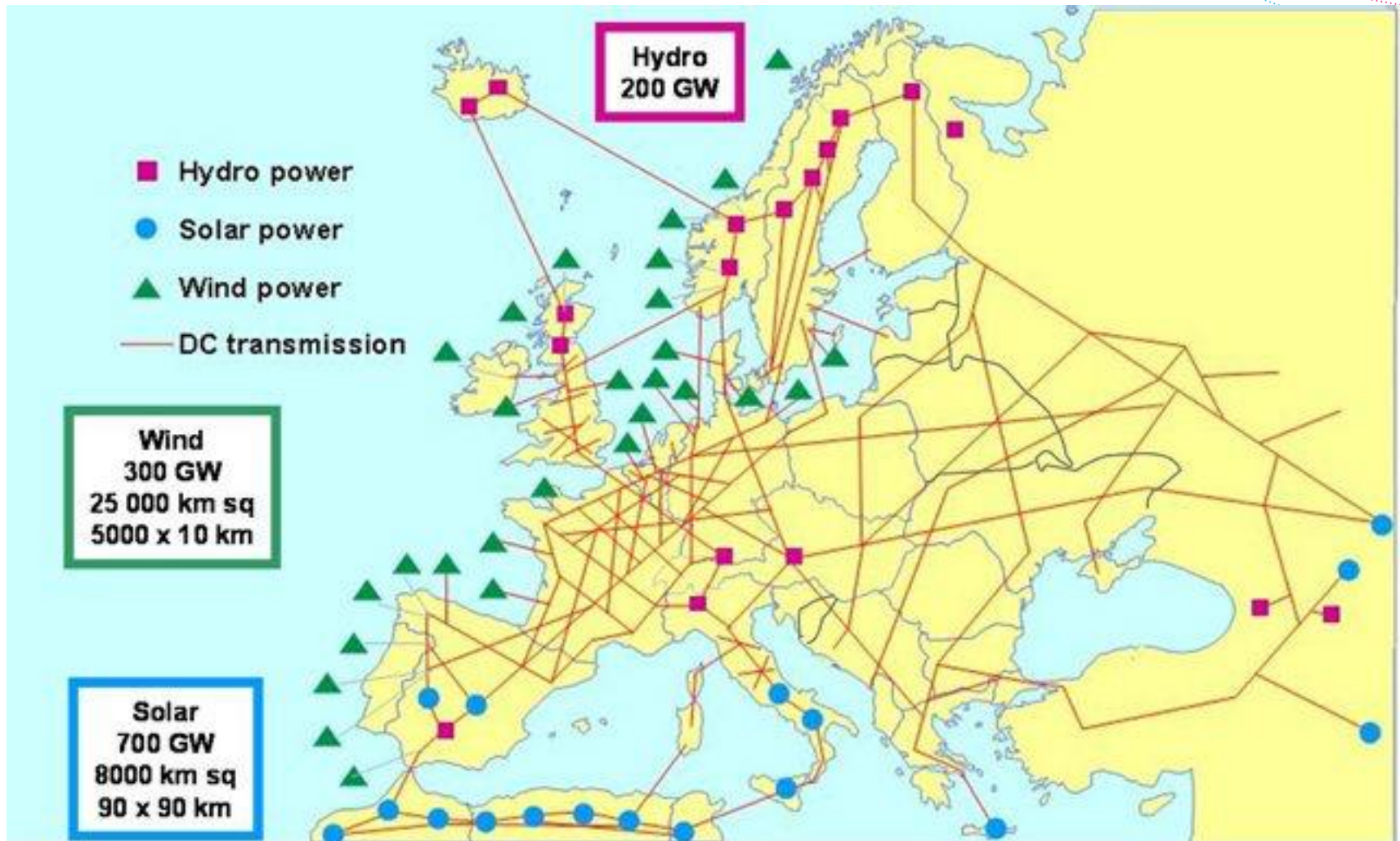
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What are the solutions going forward?

Vision from 1992..

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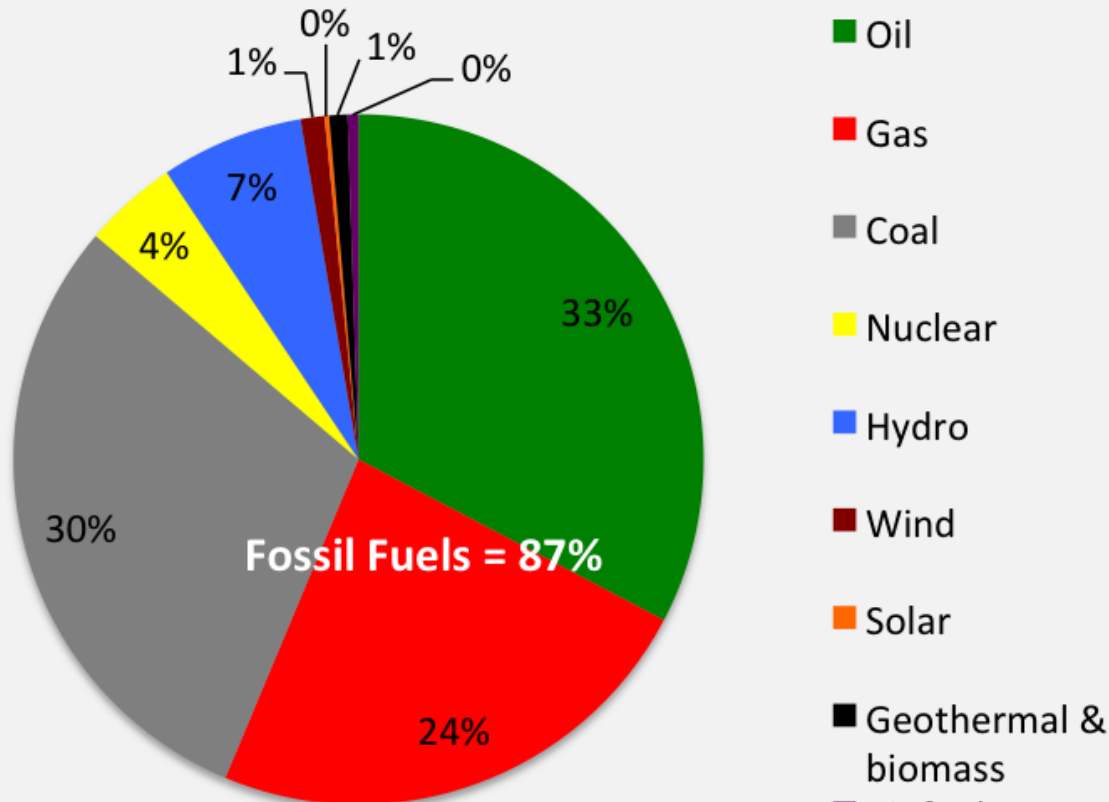


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Global energy consumption

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Global energy consumption 2013



Energy Matters
euanmearns.com
BP 2014 data

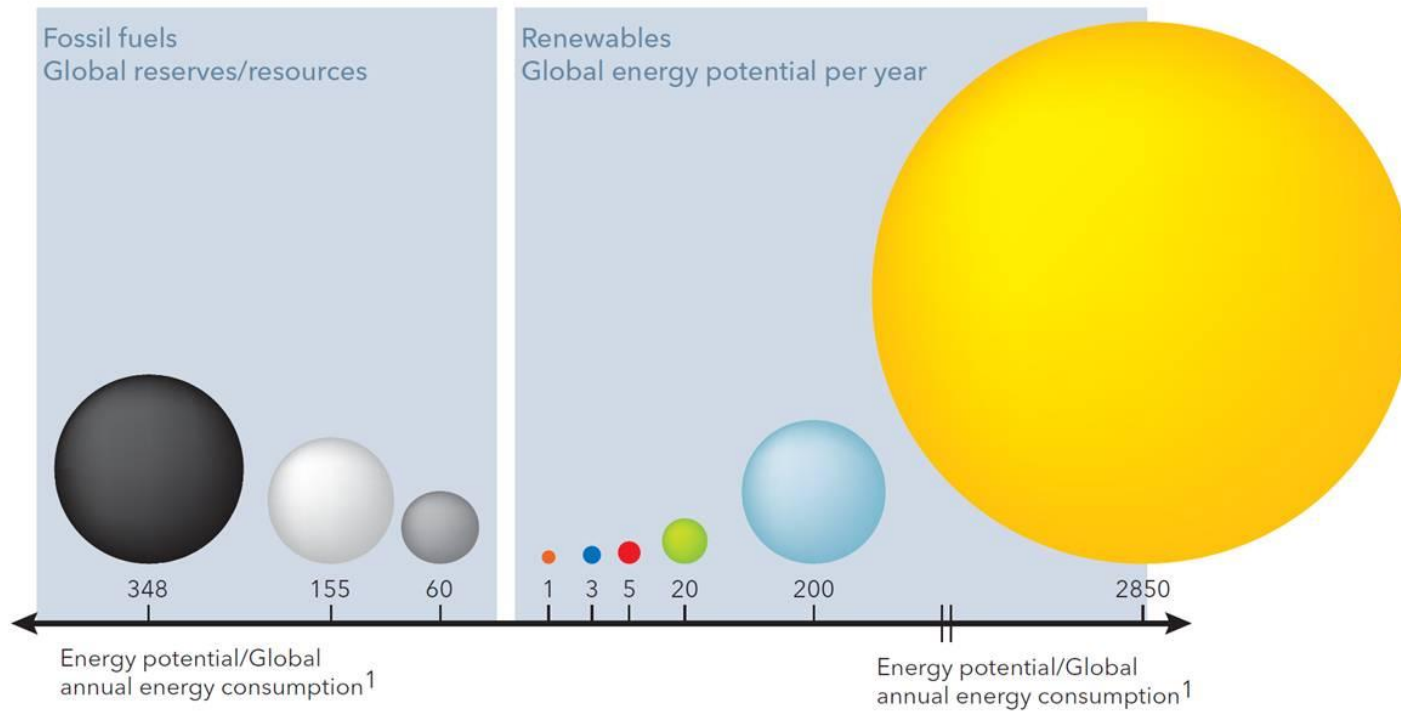
- Fossil fuels 87 %
- But all energy is not the same
- Electricity is typically **at least three to five times** more efficient in use

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Energy Options

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	Energy potential Reserves/Resources ²	Thereof conven- tionally utilizable ²
Coal	~ 135.000 EJ	
Natural gas	~ 60.400 EJ	~ 12.000 EJ
Crude oil	~ 23.000 EJ	~ 9.800 EJ
Global energy demand 2006: ~ 470 EJ		

	Energy potential (amount of energy p. a.) ²	technologically utiliz- able (state of the art) ²
Solar radiation	~ 1.111.500 EJ	~ 1.482 EJ
Wind energy	~ 78.000 EJ	~ 195 EJ
Biomass	~ 7.800 EJ	~ 156 EJ
Geothermal	~ 1.950 EJ	~ 390 EJ
Hydro/tide power	~ 1.170 EJ	~ 78 EJ

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Source: University of Twente



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Electrification is key...

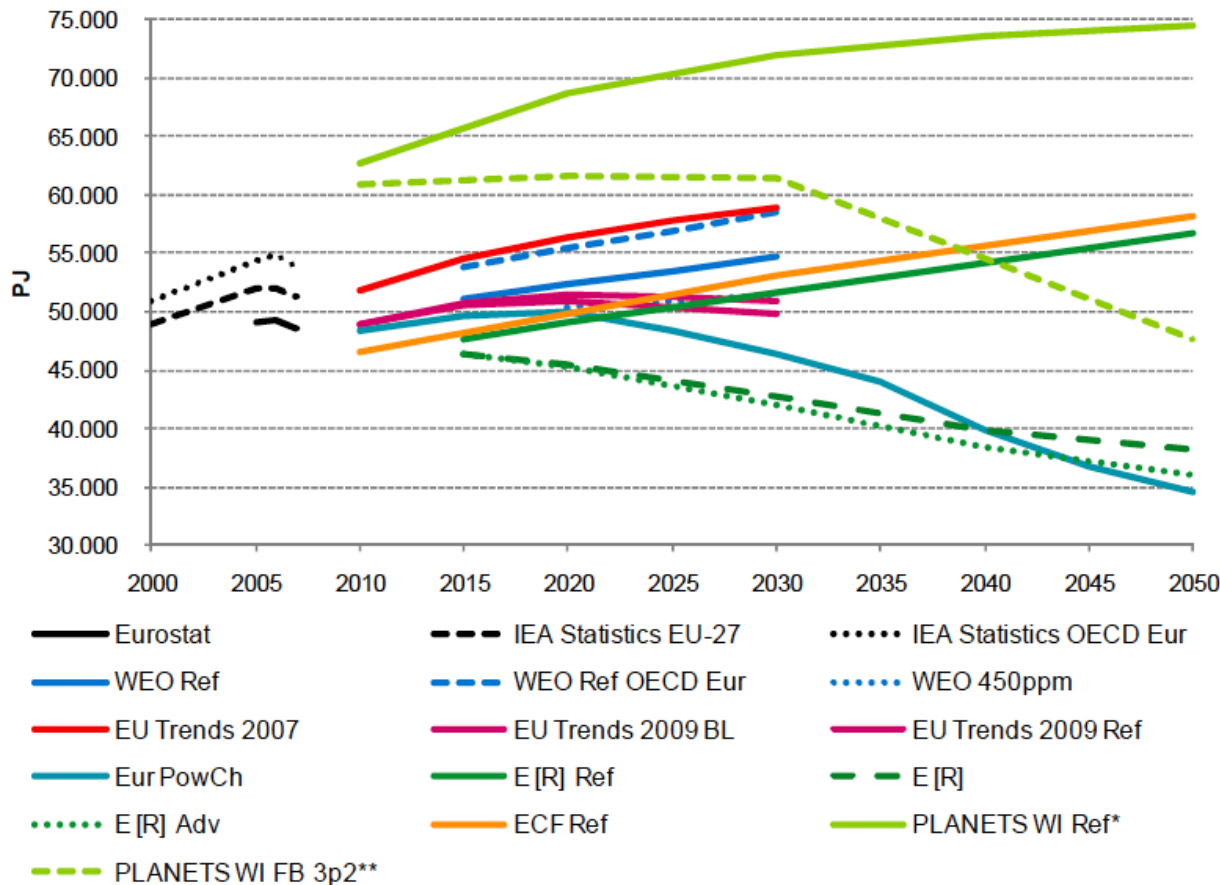


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Development of final energy demand

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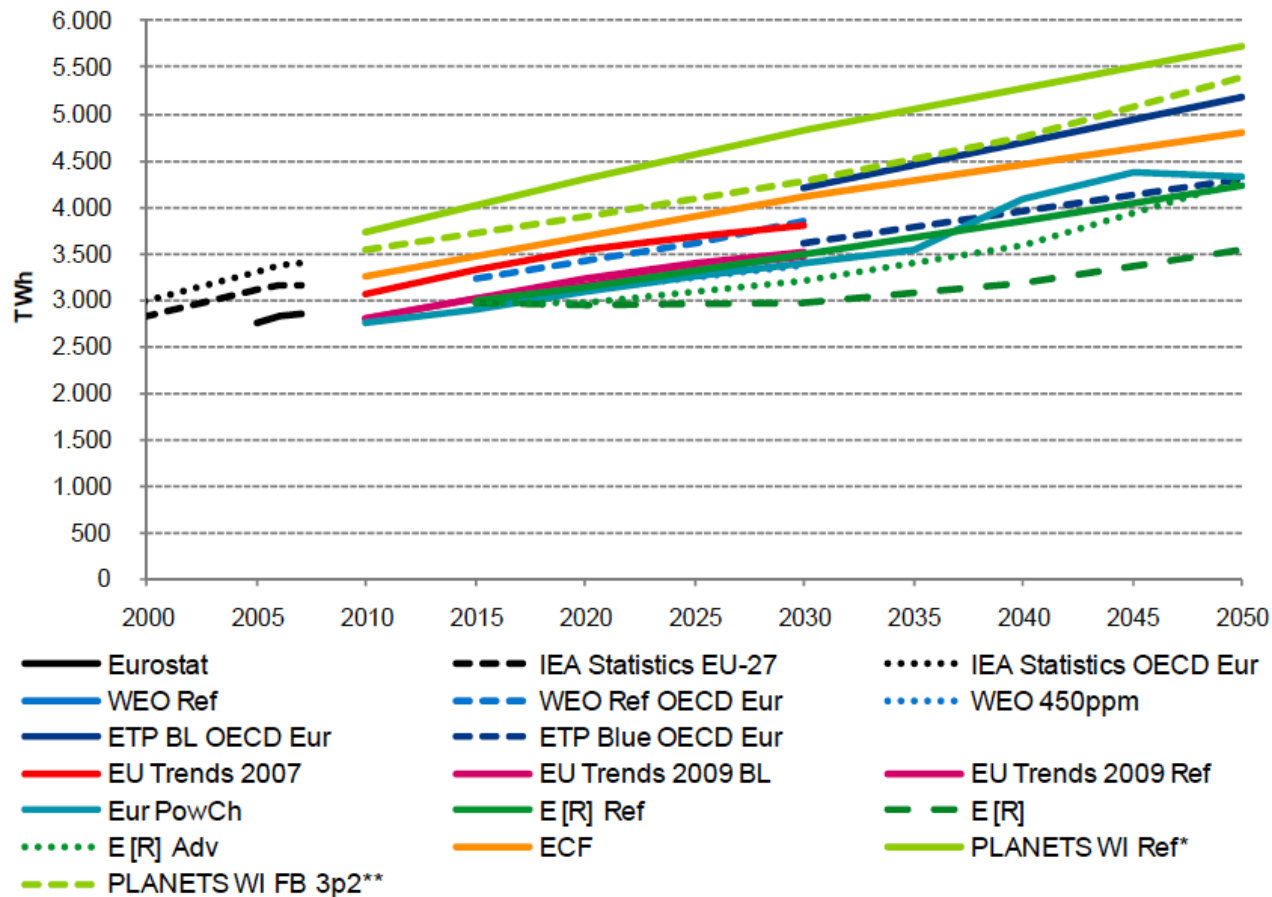
Figure 4: Development of Economy-Wide Final Energy Demand, in PJ



Development of electricity demand

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Figure 5: Development of Economy-Wide Electricity Demand, in TWh

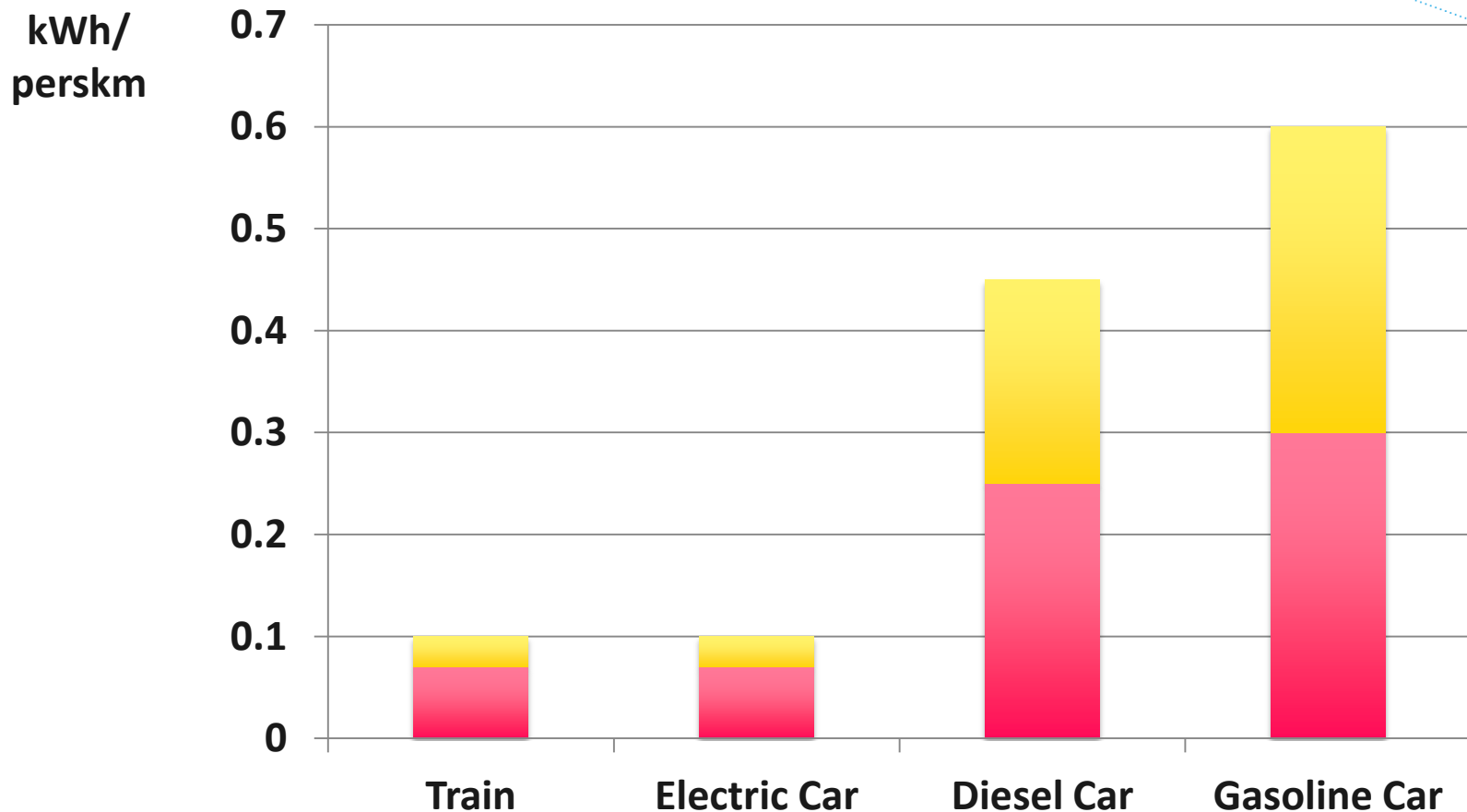


Electricity is more efficient....

Efficient transportation, electricity is 3- 5 times more efficient

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1) Energy consumption and related air pollution for Scandinavian electric passenger trains ,
Report KTH/AVE 2006:46; 40 % beläggning

2) 2 pers / bil

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Electrification of road transport, 3 – **POWER CIRCLE** 5 times more efficient

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TRAFIKVERKET
SWEDISH TRANSPORT ADMINISTRATION



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Electrification of heat sector with heat pumps

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1 kWh electricity gives 4 - 5 kWh heat

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Electricity is more efficient, 24 times more efficient...

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	Battery	Gasoline
Cutting	43 cm	46 cm
Weight	14 kg	31 kg
Sound level	66 dB	77 dB
Battery / Gas tank	0,1 kWh	9 kWh
Operation time	0,3 tim	1,2 tim
Energy / hour	0,3 kWh	7,5 kWh
Relative consumption	1	24



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Electric lighting dramatically more efficient than oil...

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re sustainable energy



1



20 - 30



100 - 200

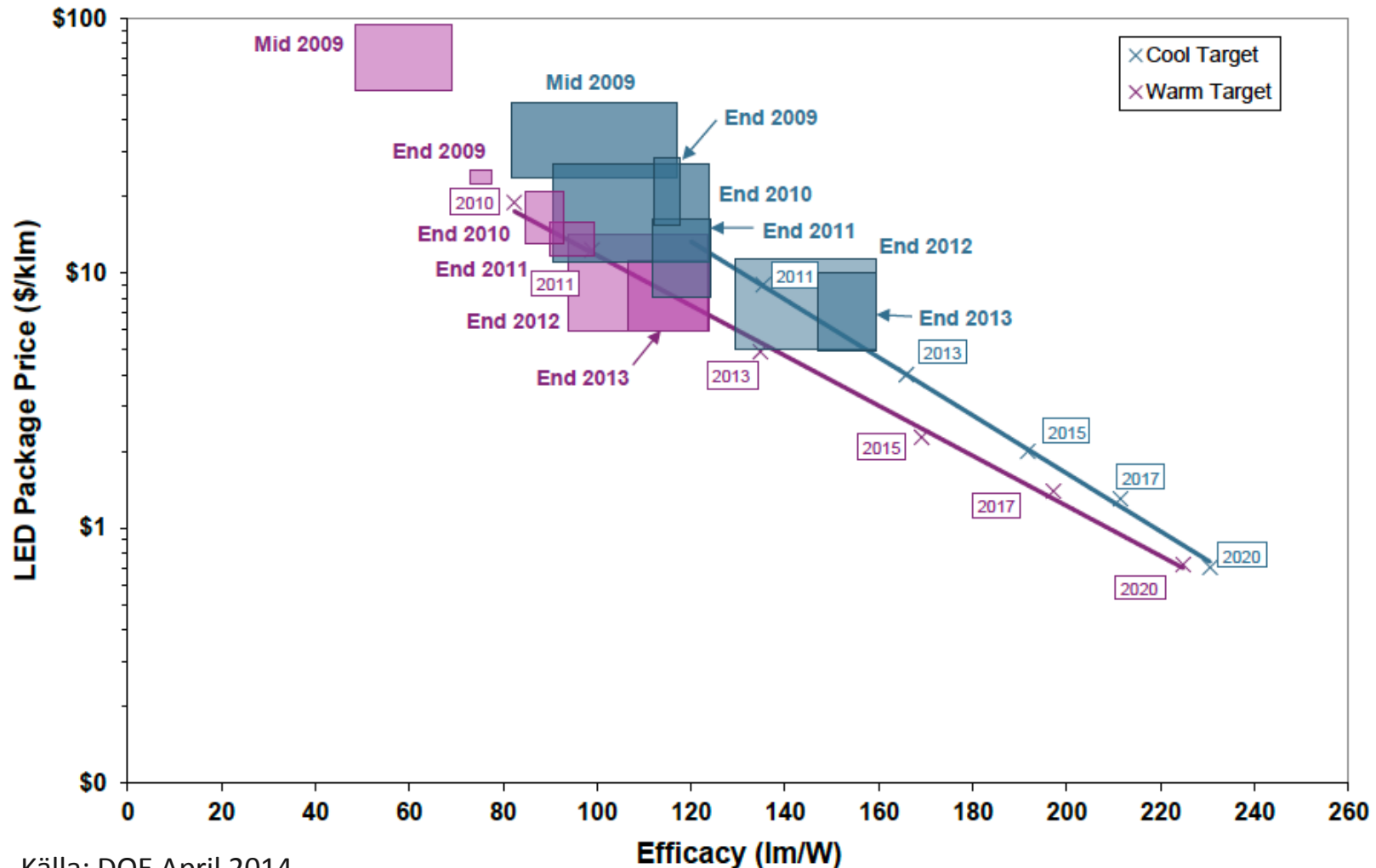


300 - 500

Development continues...

Cost / efficiency LED

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Källa: DOE April 2014

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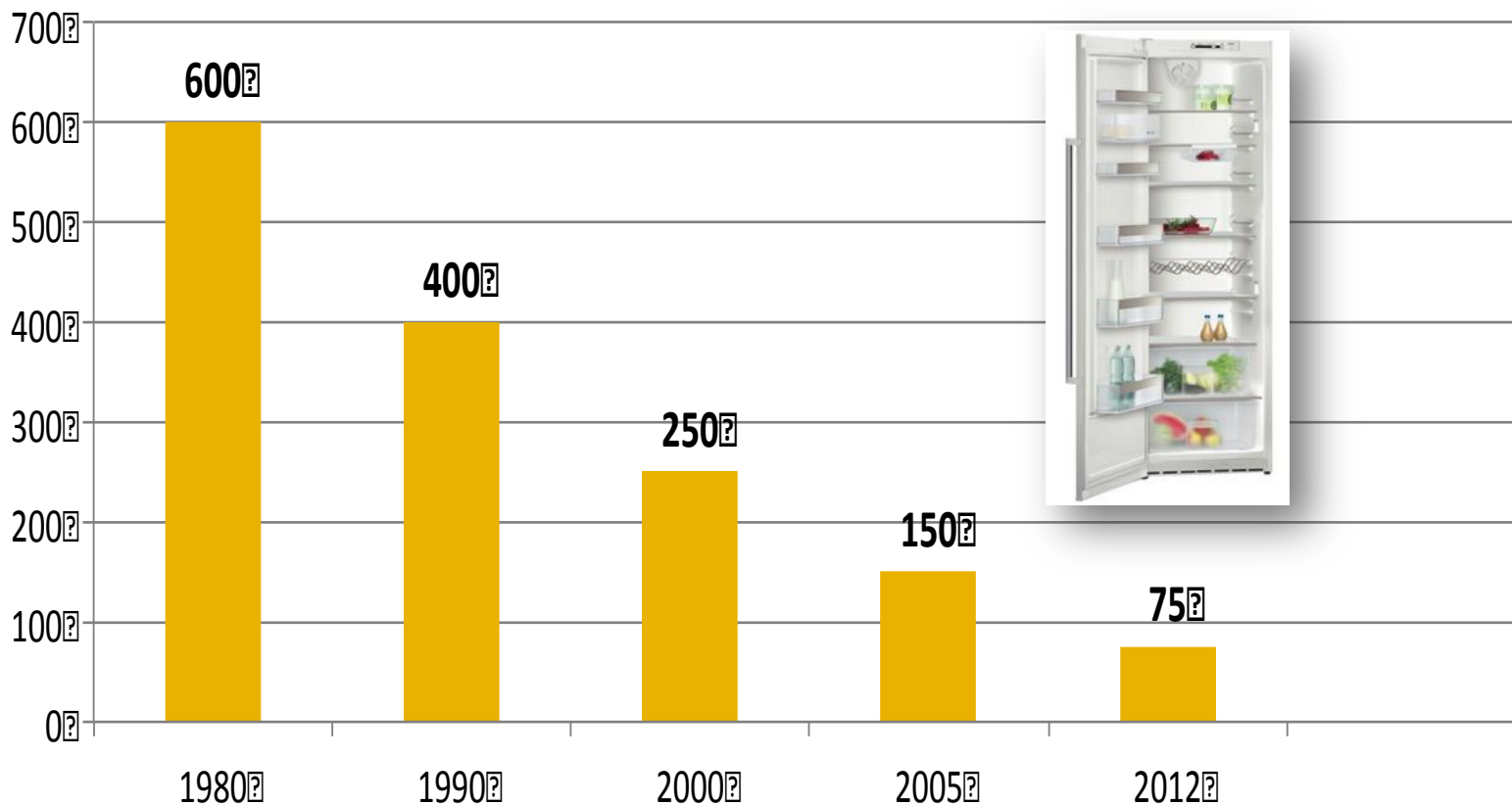
Best in class refrigerator

kWH per year, 8 times better..

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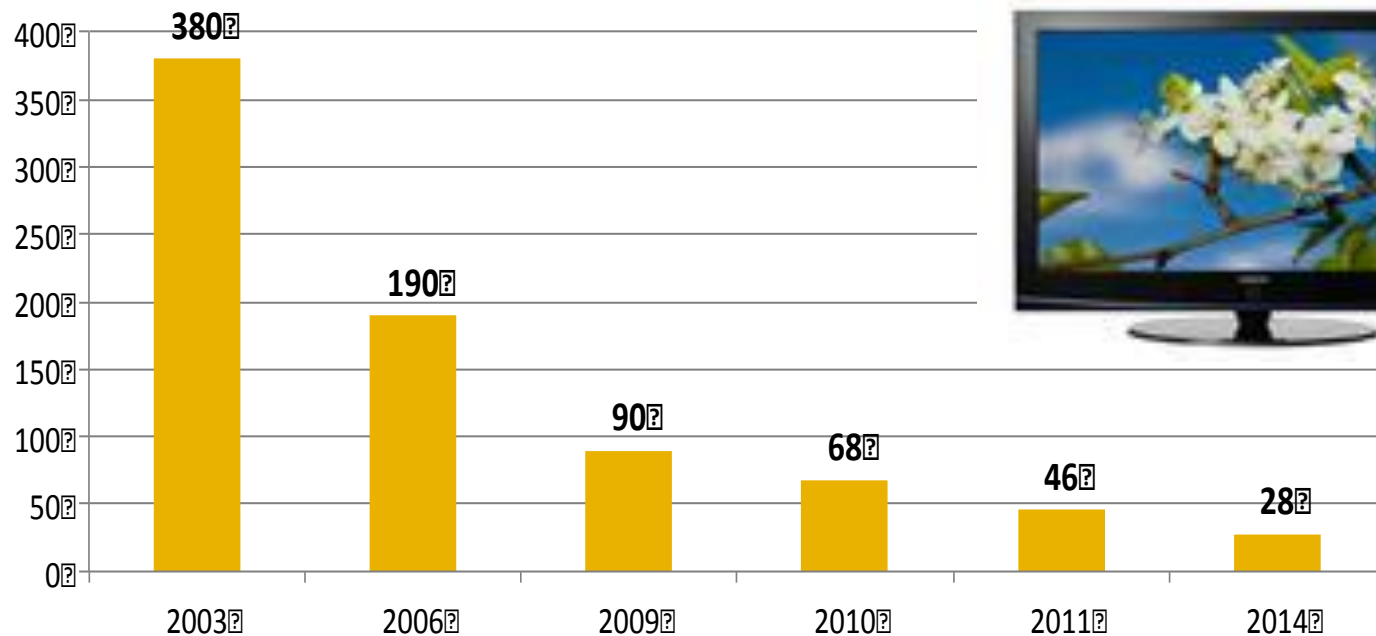
Average Power 8 W



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Best in class 40" flatscreen TV more than 10 times better...

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Plasma

LCD

LED

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But than we have
the rebound effect...

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PV Solar



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Vanguard I, 1958

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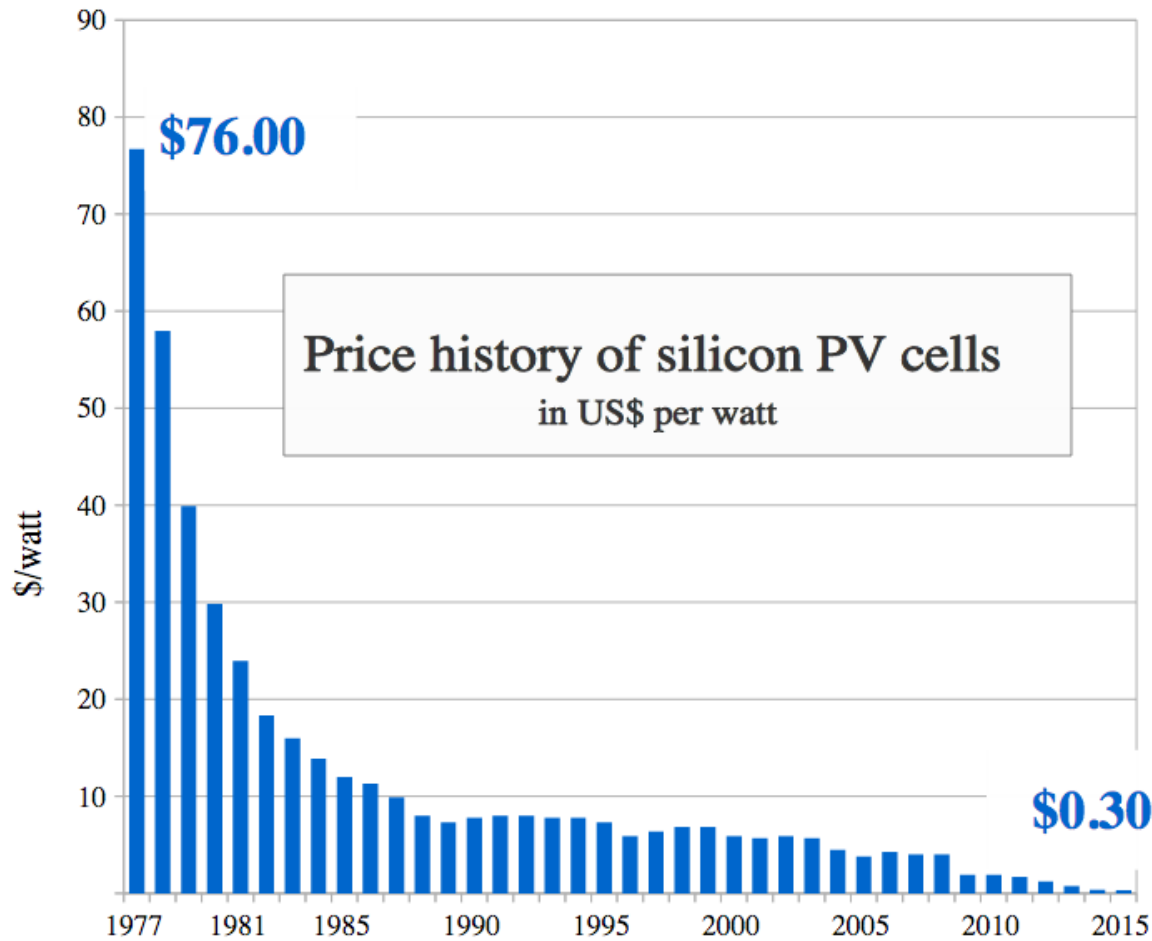
Solar cells gained prominence with their incorporation onto the 1958 Vanguard I satellite.



The spacecraft was a 1.47-kg aluminum sphere 16.5 cm in diameter. It contained a 10-mW, 108-MHz mercury-battery powered transmitter and a 5-mW, 108.03-MHz transmitter **powered by six square (roughly 5 cm on a side) solar cells mounted on the body of the satellite**

Price history PV

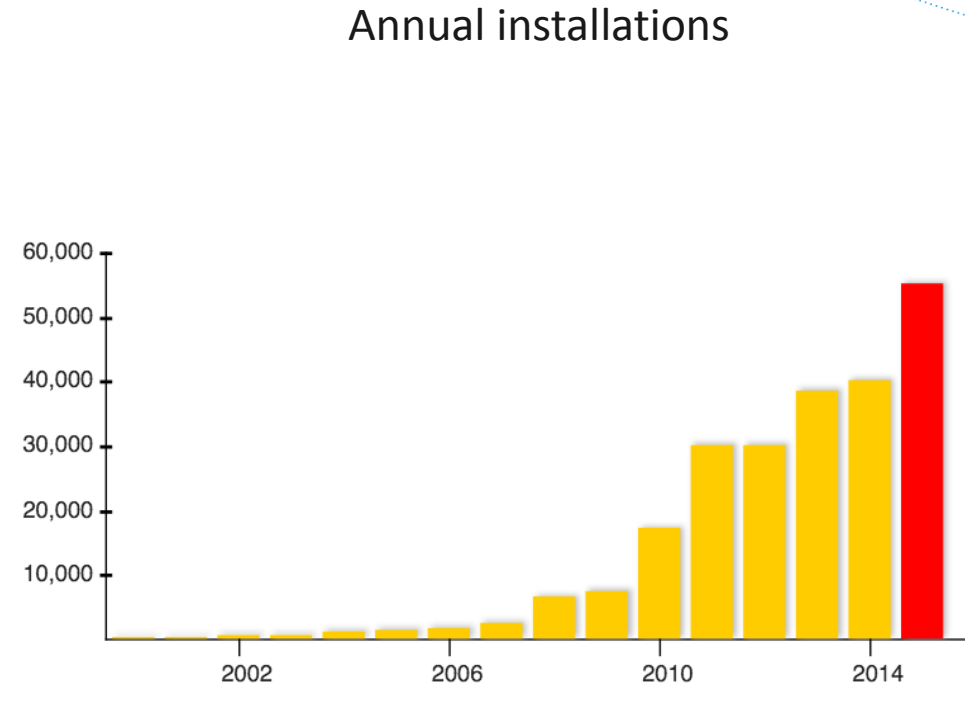
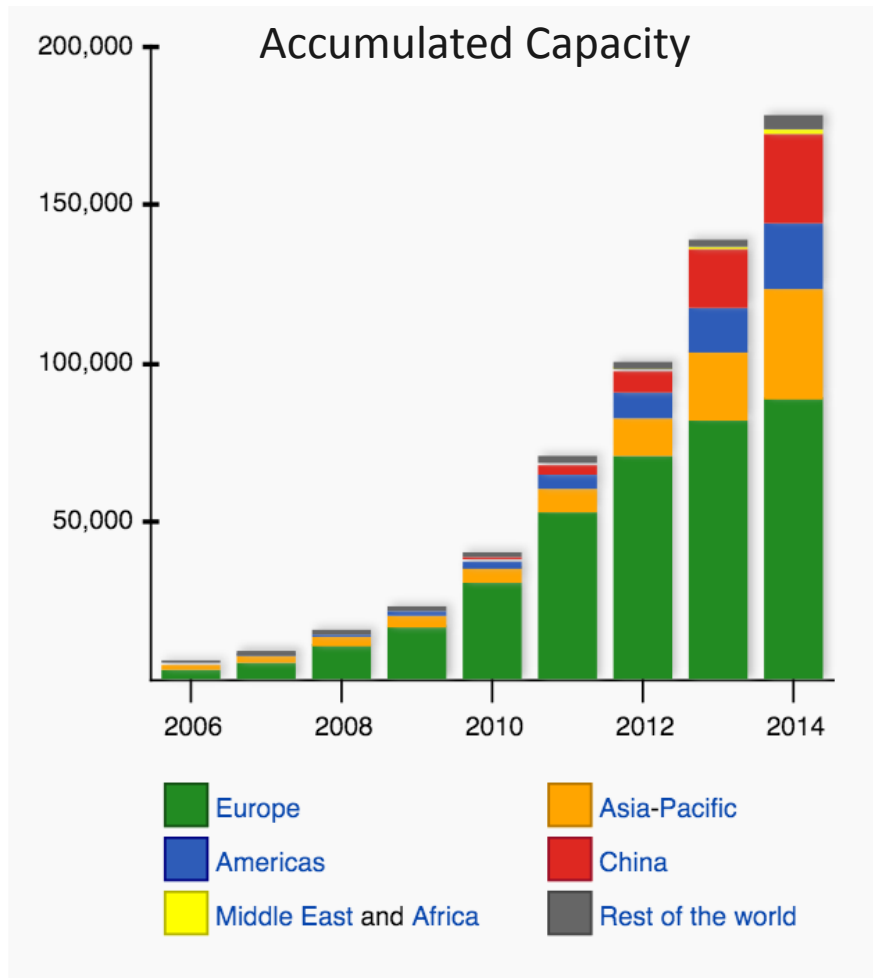
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Source: Bloomberg New Energy Finance & pv.energytrend.com

Source: Wikipedia

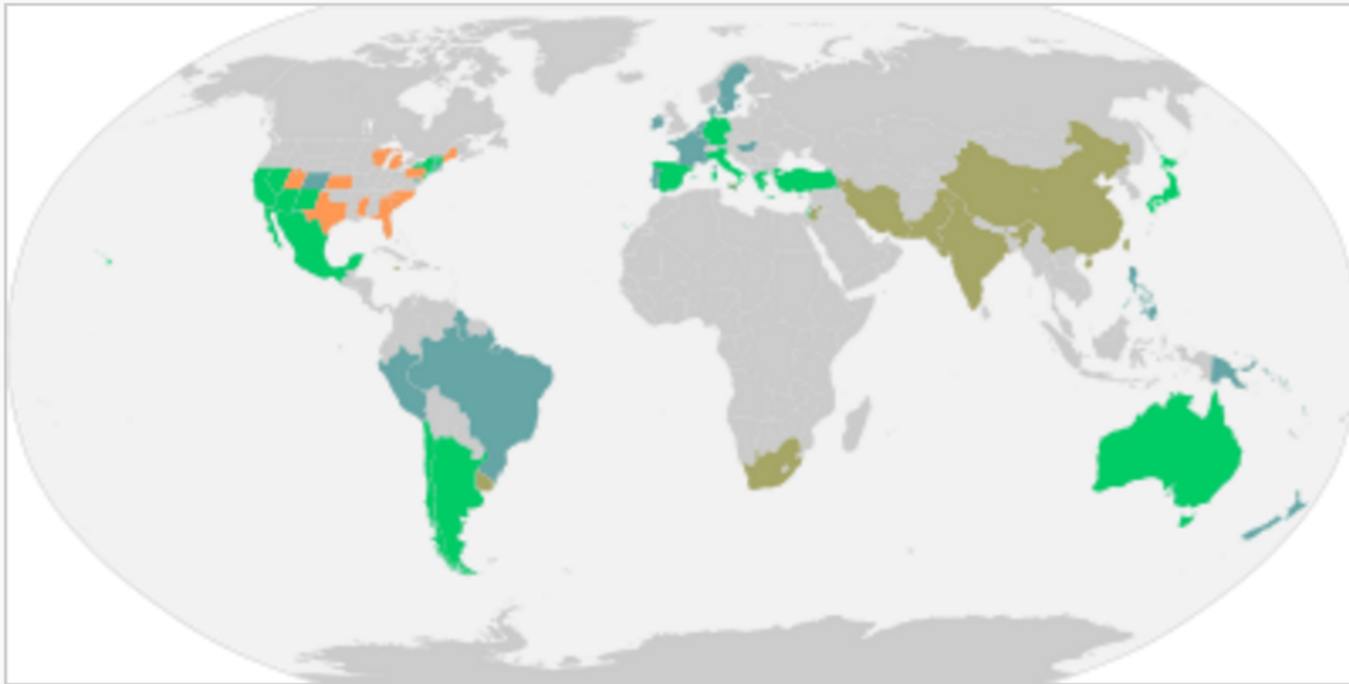
Global installed PV capacity



Regions that have reached grid parity for PV

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Grid parity for solar PV systems around the world

- Reached grid-parity before 2014
- Reached grid-parity after 2014
- Reached grid-parity only for peak prices
- U.S. states poised to reach grid-parity

Source: Deutsche Bank, as of February 2015

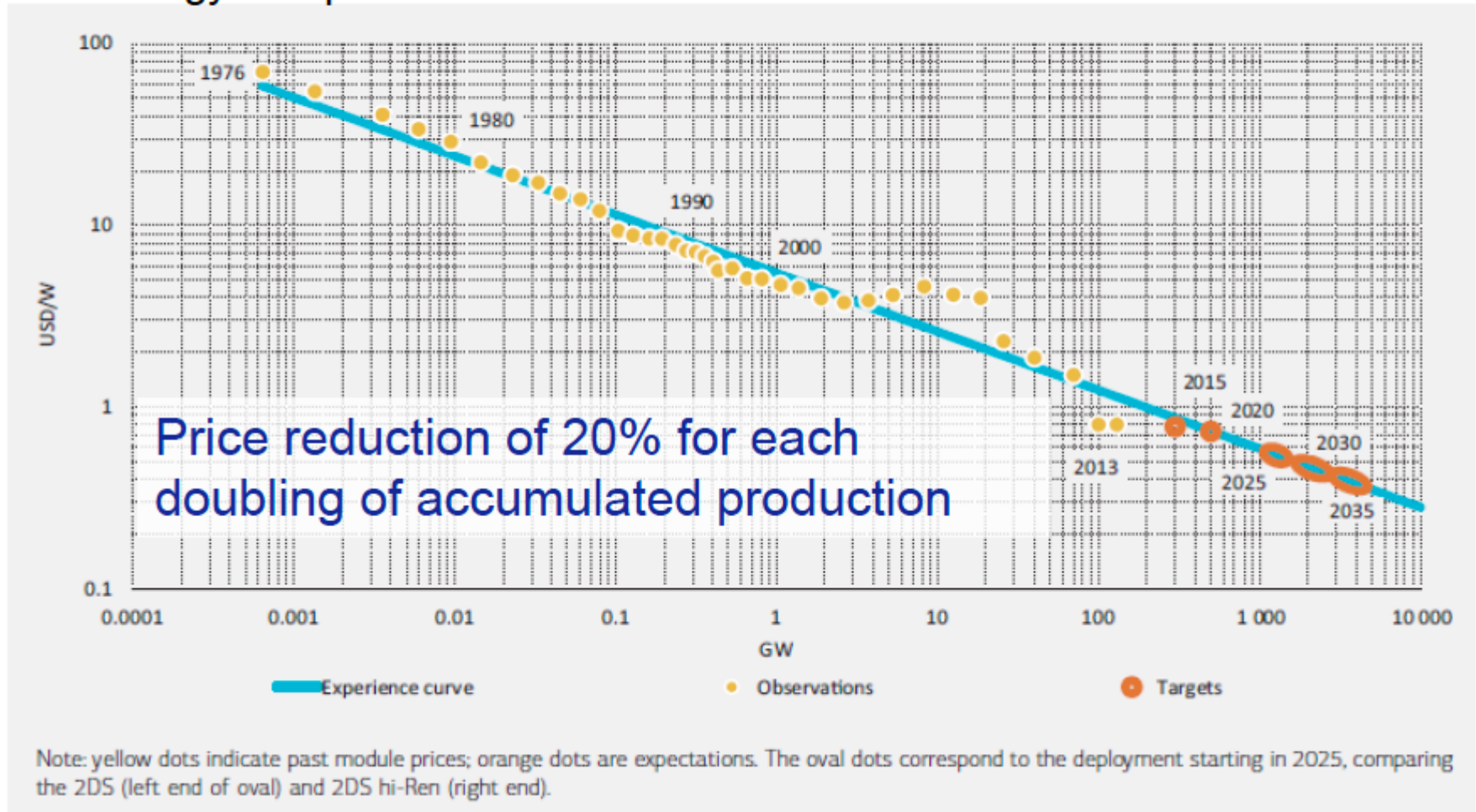


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And the development will continue

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Experience curve for PV modules and extension to 2035 in the IEA Energy Technology Perspectives 2014 - 2DS scenario



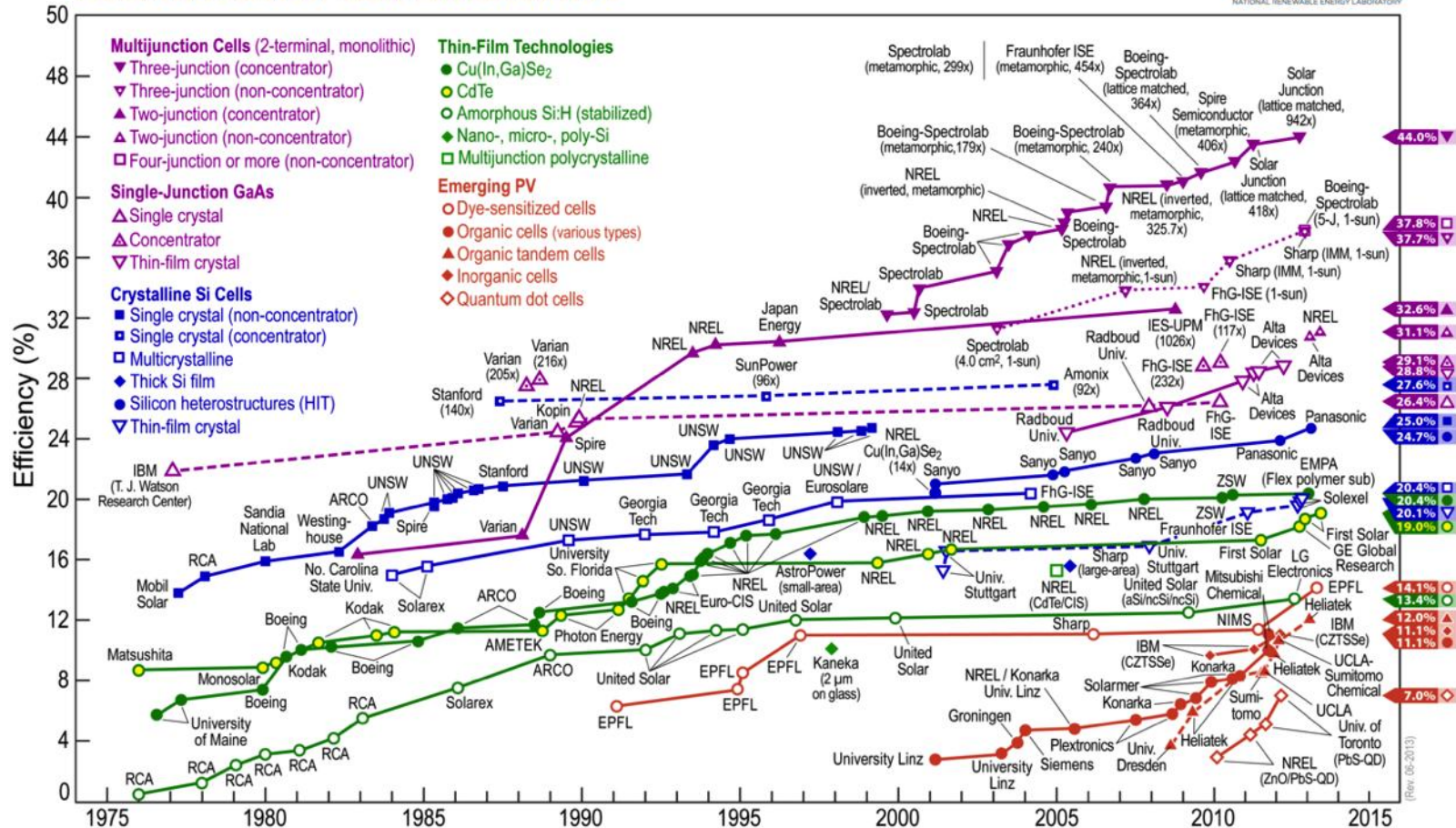
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How efficient can PV solar become?

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Best Research-Cell Efficiencies

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



(Rev. 06-2013)

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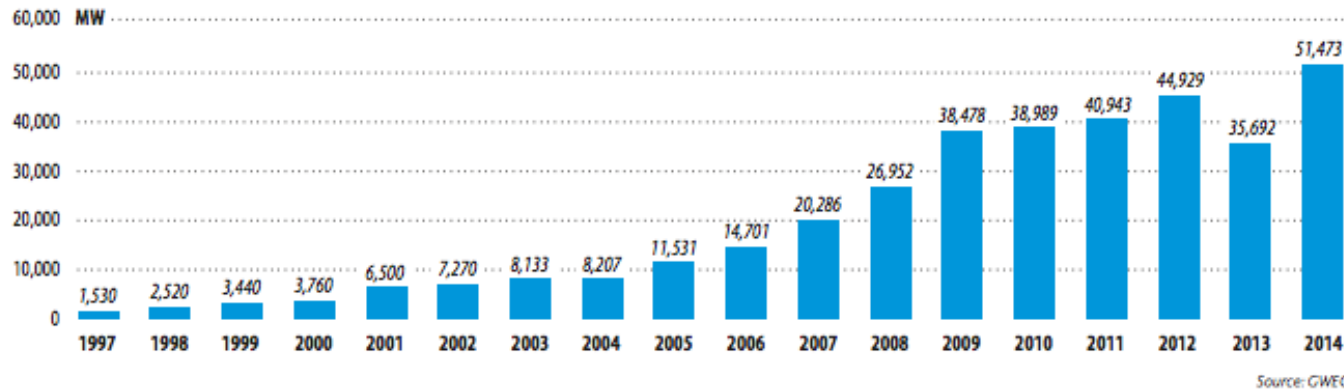
Wind

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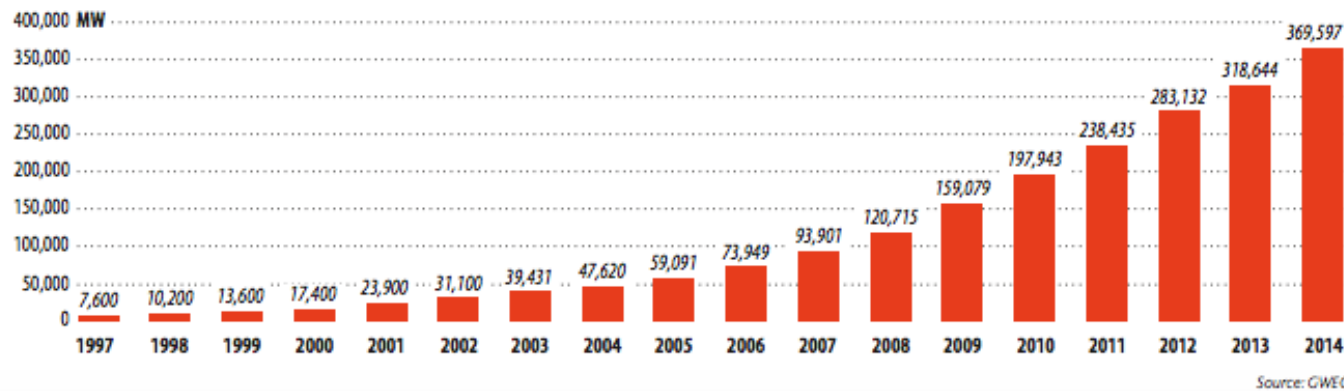
Global wind power

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GLOBAL ANNUAL INSTALLED WIND CAPACITY 1997-2014



GLOBAL CUMULATIVE INSTALLED WIND CAPACITY 1997-2014

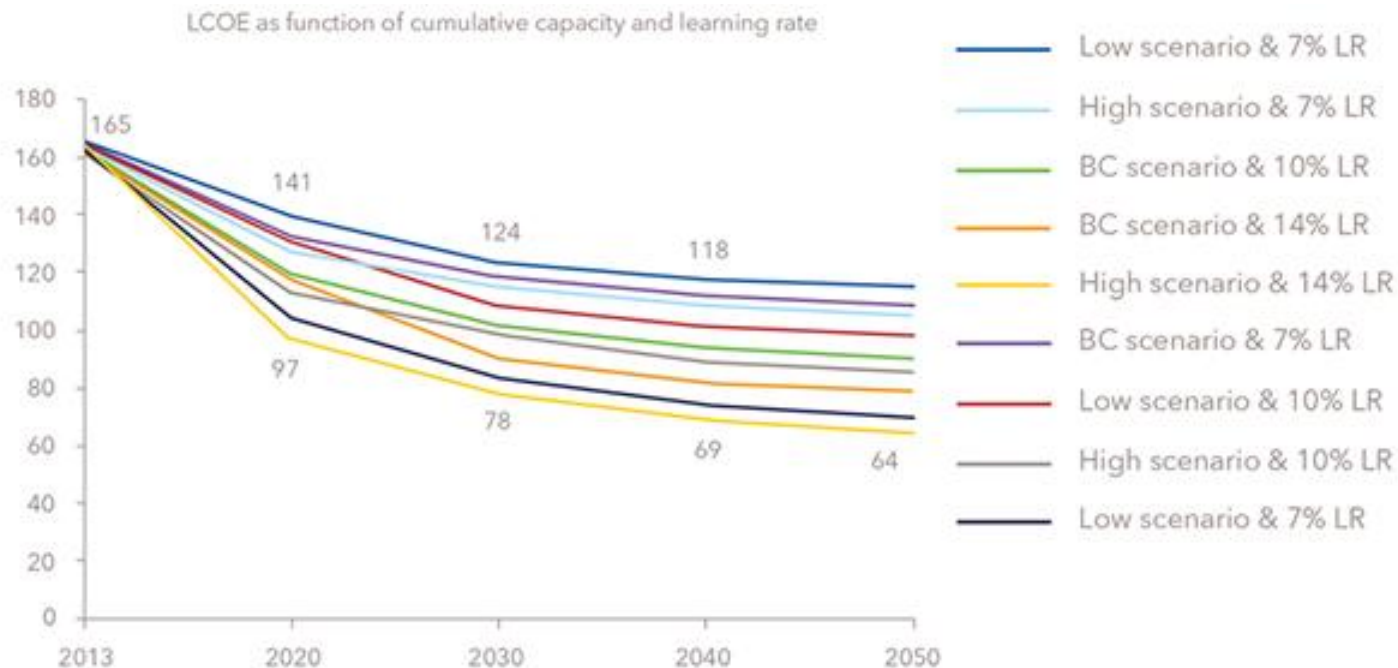


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Economy of volume off shore wind turbines

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Costs will drop by 10 – 14 % for every doubling of installed capacity..



Wind power is largescale and requires a stronger grid

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Enabling technology Power transmission

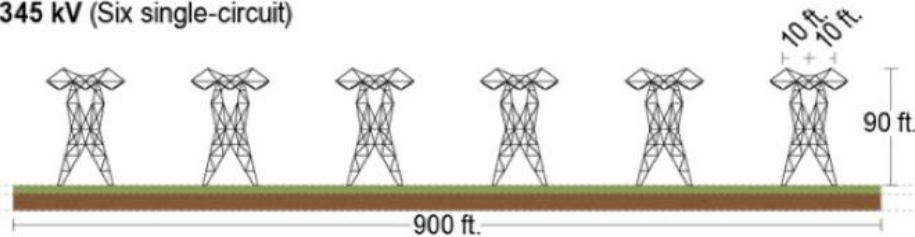
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Power transmission alternatives 6000 MW

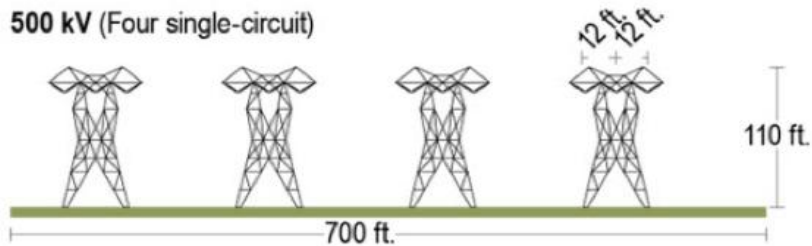
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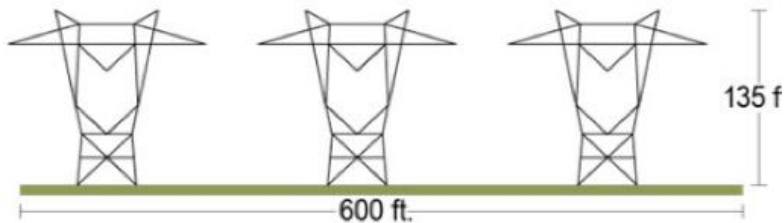
5,000 MW Capacity
345 kV (Six single-circuit)



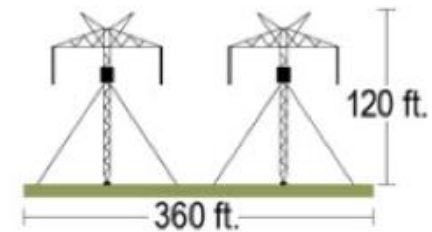
500 kV (Four single-circuit)



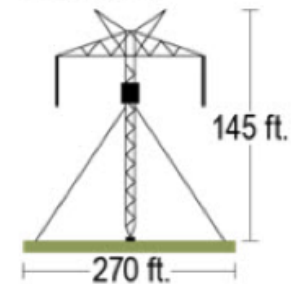
6,000 MW Capacity
765 kV AC (Three single-circuit)



500kV DC



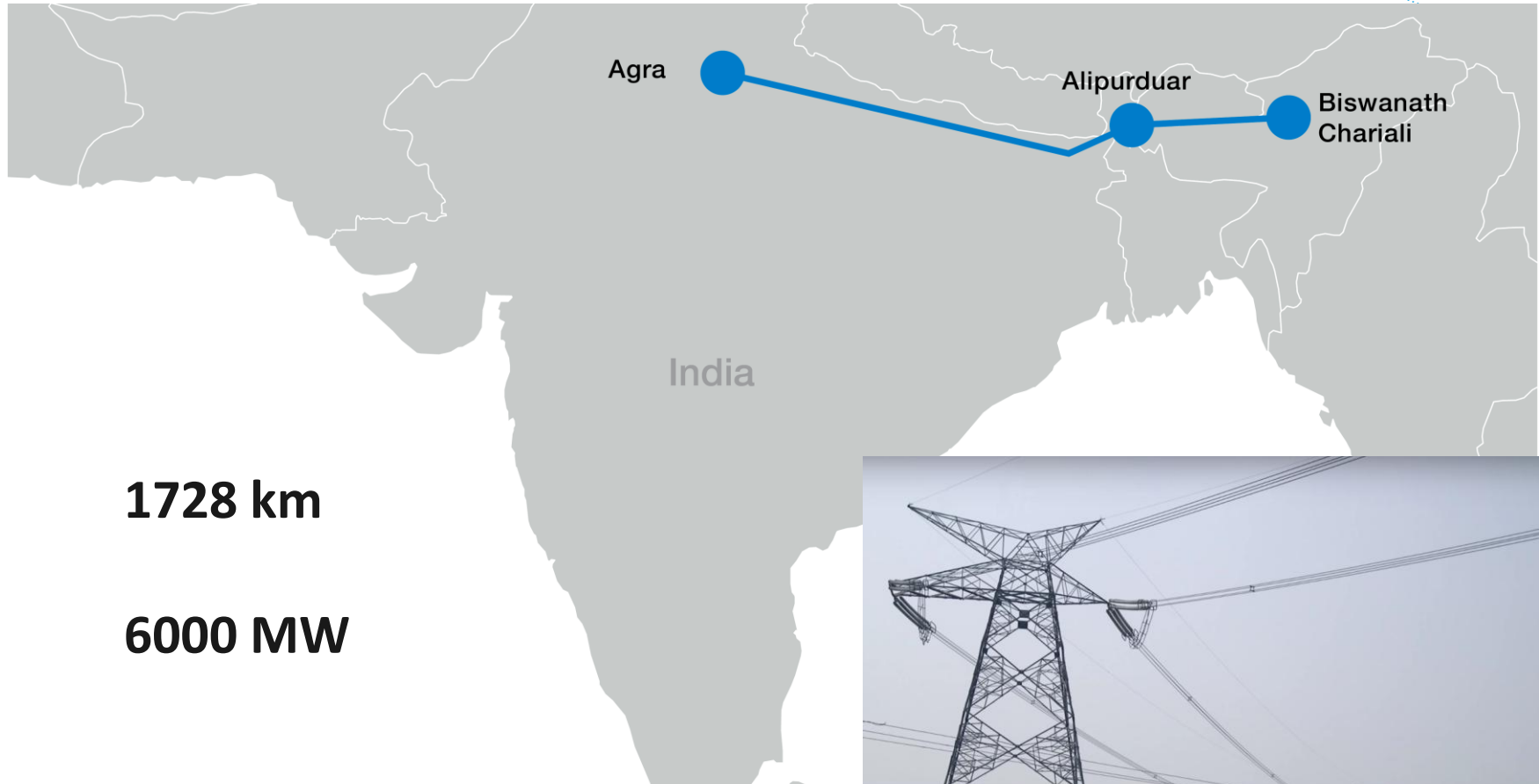
800kV DC



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India is building UHVDC transmission

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1728 km

6000 MW



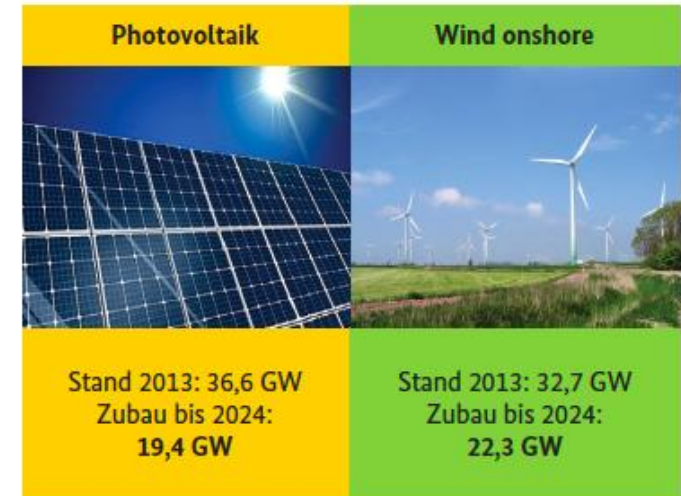
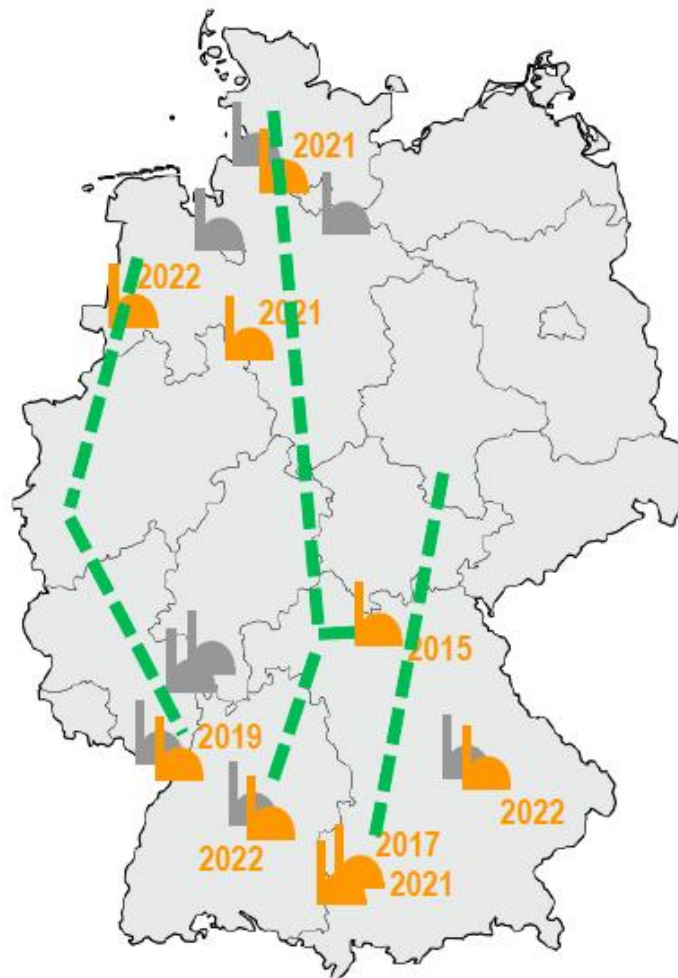
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Germany has decided on HVDC Corridors


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Warum Netzausbau? Randbedingungen



(Zahlen entsprechen dem Szenario B2024
abzüglich der Offshore-Reduktion)

 HGÜ-Korridor

Kernkraftwerke

 geplante Abschaltung

 abgeschaltet

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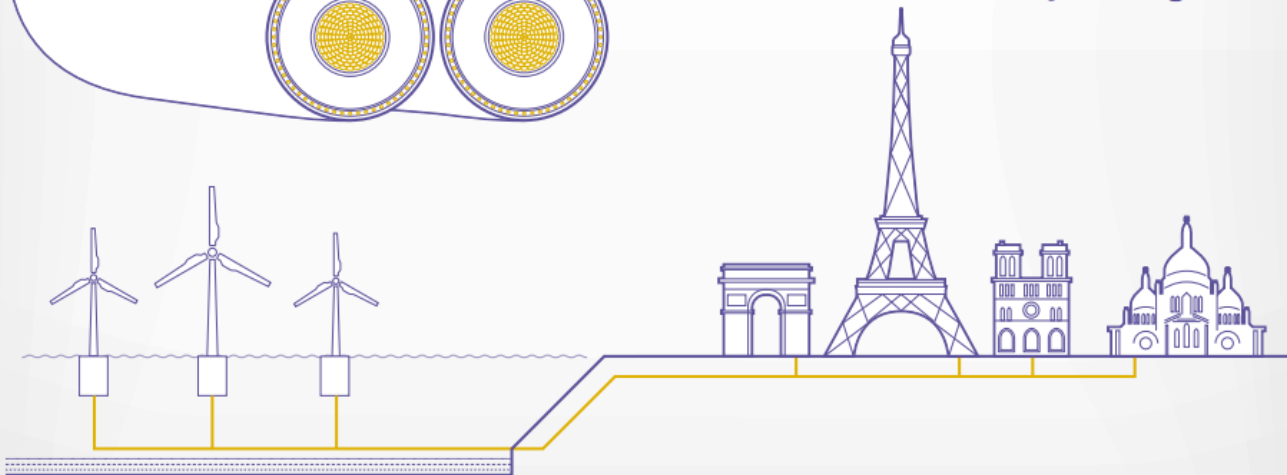
Development of power transmission cables

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A single pair of ABB's latest 525kV HVDC extruded cable will be able to transmit up to 2.6 GW of power from renewable energy resources

2.6 GW capacity

... enough to serve the electricity needs of
Paris, City of Lights



Power and productivity
for a better world™

ABB


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Enabling technology Forecasting

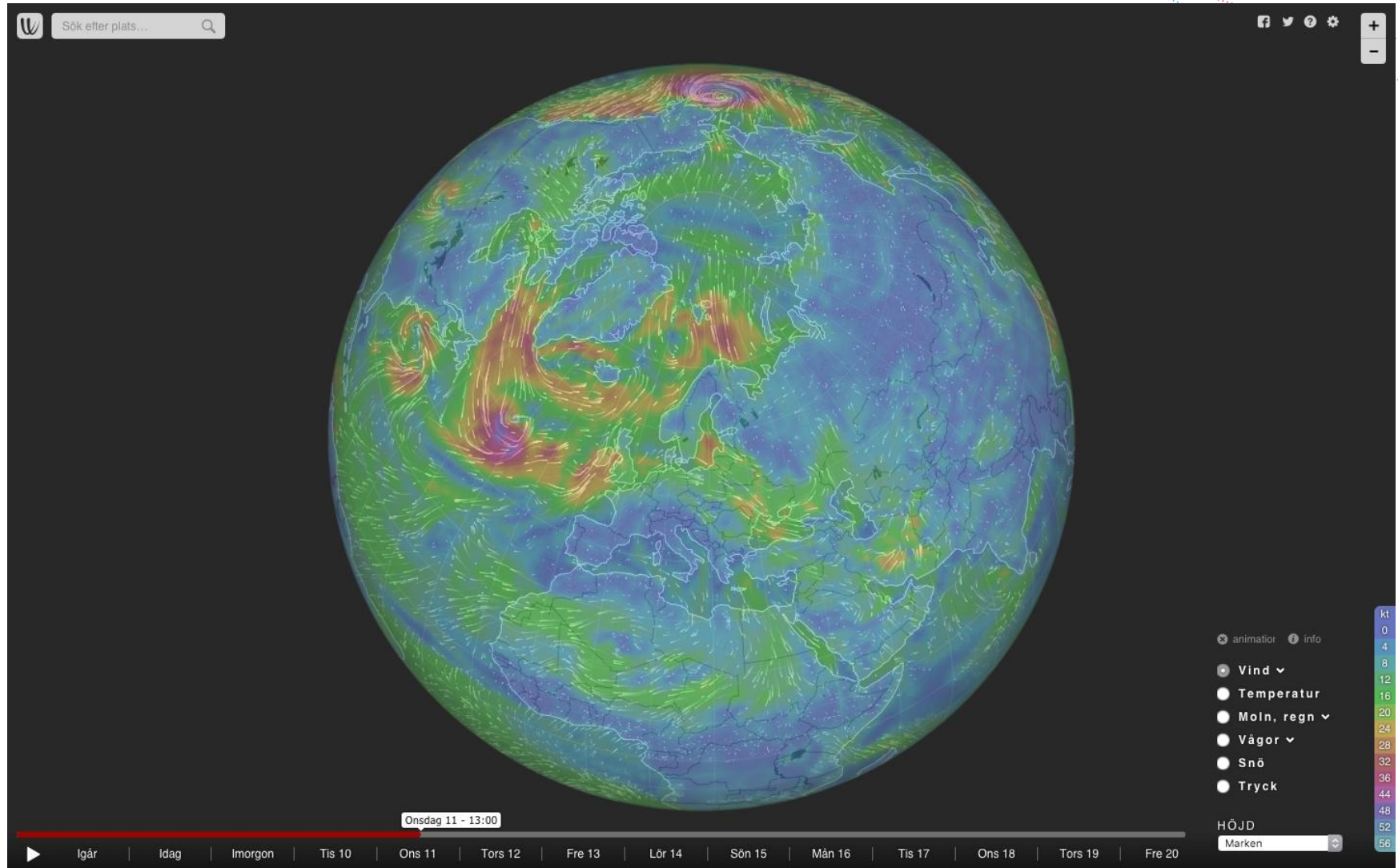


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Wind forecasting

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Solar forecasting

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steadySat structure

EXPERT **steadysun**, configuration, optimized solution

SATELLITE IMAGES

(MeteoSat, GOES East,
GOES West, MSAT, etc...)



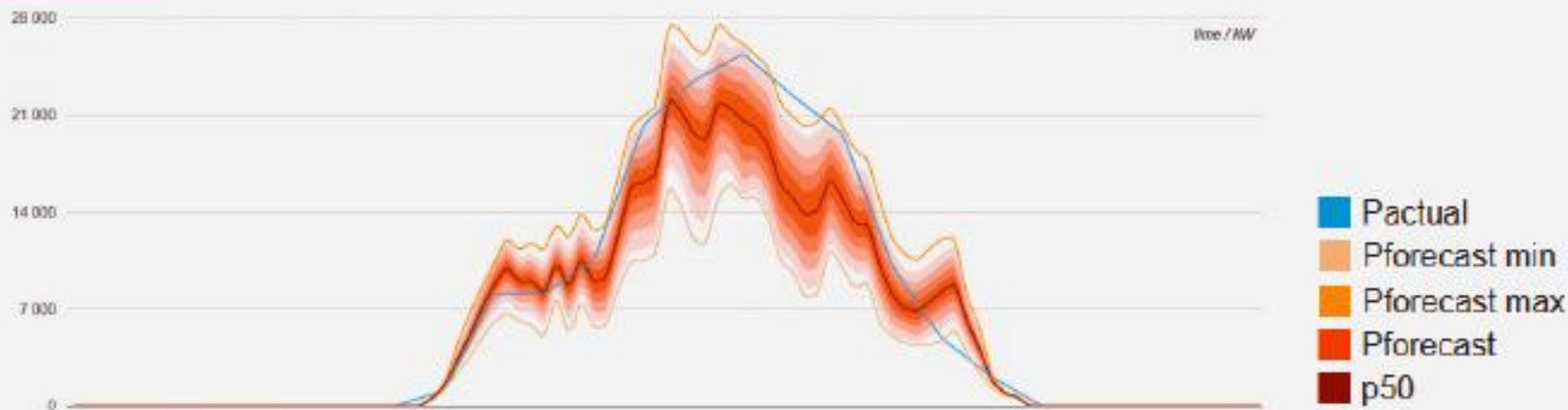
> Data RECEPTION
et TREATMENT,
modelling

STEADYSUN
ALGORITHM

LEARNING

- > SOLAR PRODUCTION FORECAST from 0 to 6 hours
- > TIME INCREMENT from one minute
- > UPDATED UP TO 96 TIMES / DAY

Forecast for an island (36MW) with quantiles




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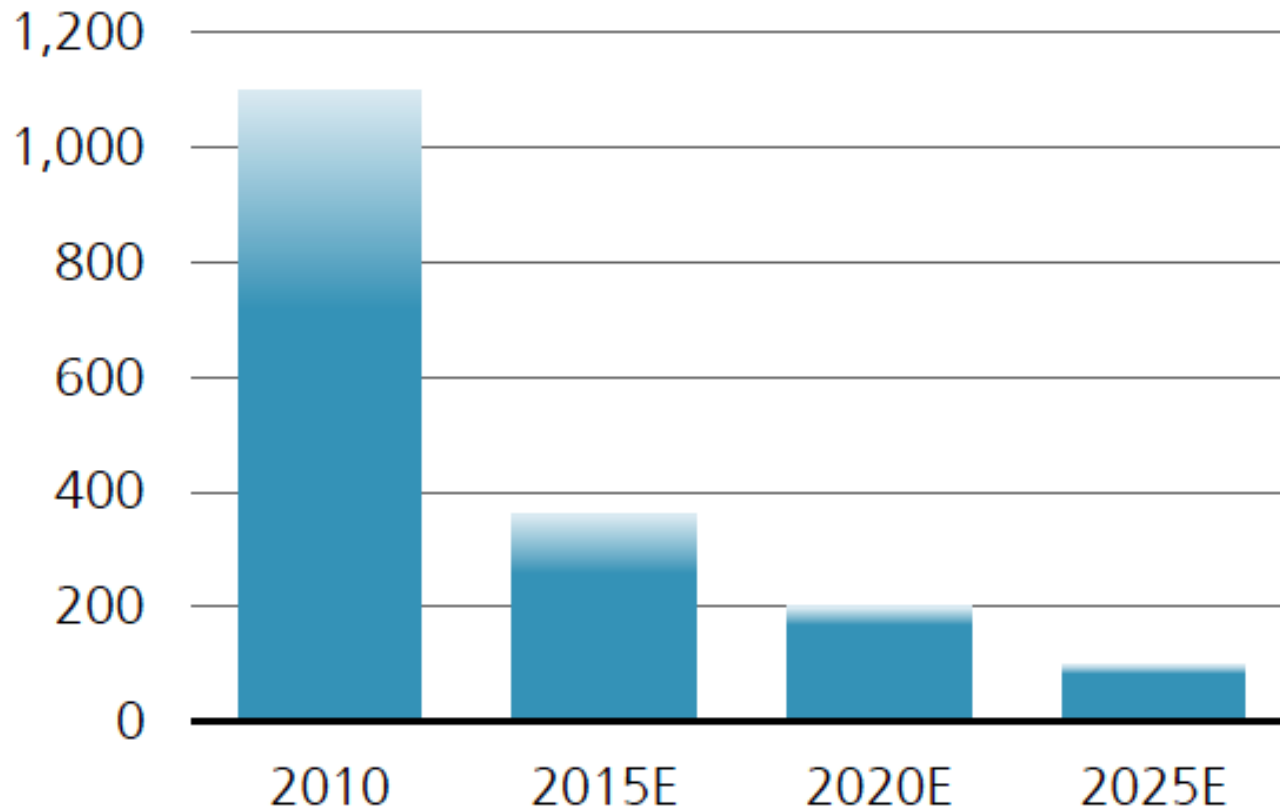
Enabling technology Batteries



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Cost development batteries

Figure 2: Lithium battery cost to decline >50% by 2020



Source: Tesla, Umicore, UBSe. Cost estimates are for the battery pack (€/kWh).

D. Ristori (DG ENER) at a high-level roundtable on storage at the EC (19.05.2015)

- Storage should be at the heart of the internal market and become the **top priority** for the energy system in the EU.
- Storage has been **underestimated** for long, and it should change rapidly.
- The EU will **use all the tools available** to support storage development, such as Horizon 2020

Stakeholders at a high-level roundtable on storage at the EC (19.05.2015)

- **EDSO:** We will need storage at whatever cost with an increase of the share of RE.
- **RTE:** we should stop focussing on conventional economic analysis when it comes to storage
- **Eurelectric:** for a new market design, we should start from this rule: everyone going to the grid should be balanced. No more simple injection of electricity in the grid.

Tesla

New entrant in power business

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- Powerwall for household 350 \$ / kWh
- Powerblock for utilities 250 \$ / kWh



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Battery development continues

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From 140 Wh / kg to 1000 Wh / kg



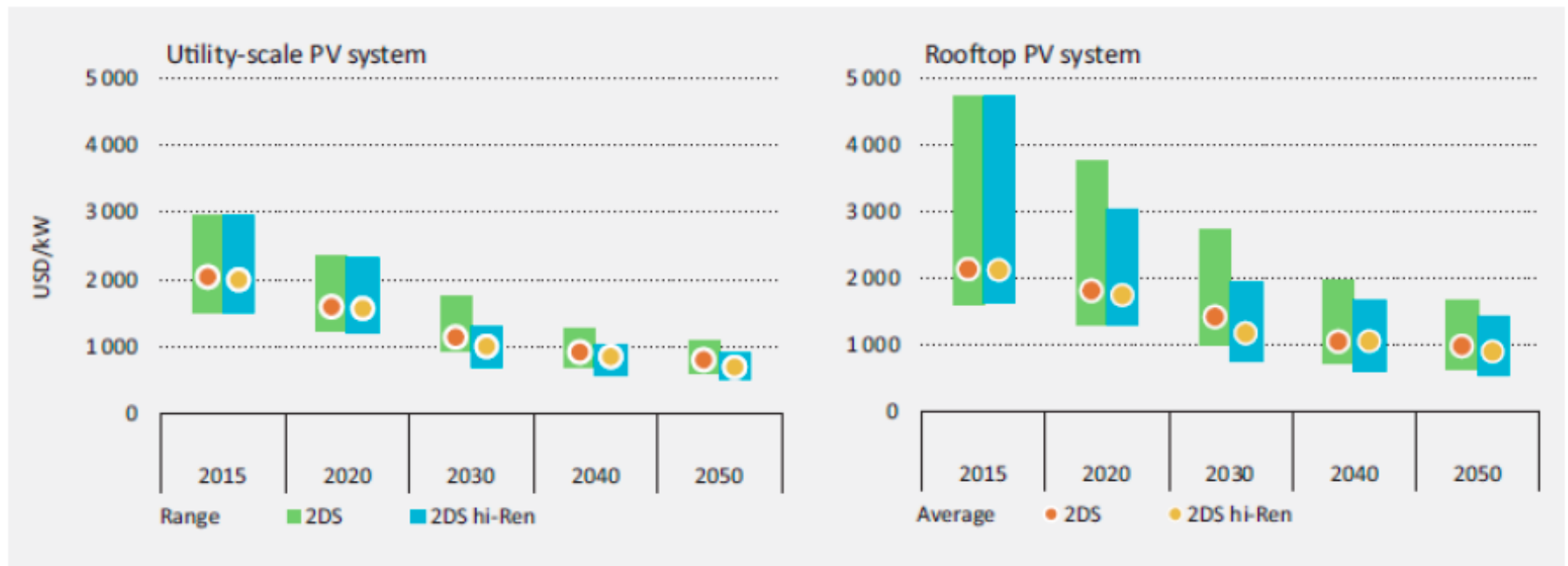
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Small scale or large scale ?

Economy of **scale**, PV systems

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Investment costs of utility scale and rooftop PV systems in the IEA Energy Technology Perspectives 2014 - 2DS and the 2DS hi-Ren scenarios

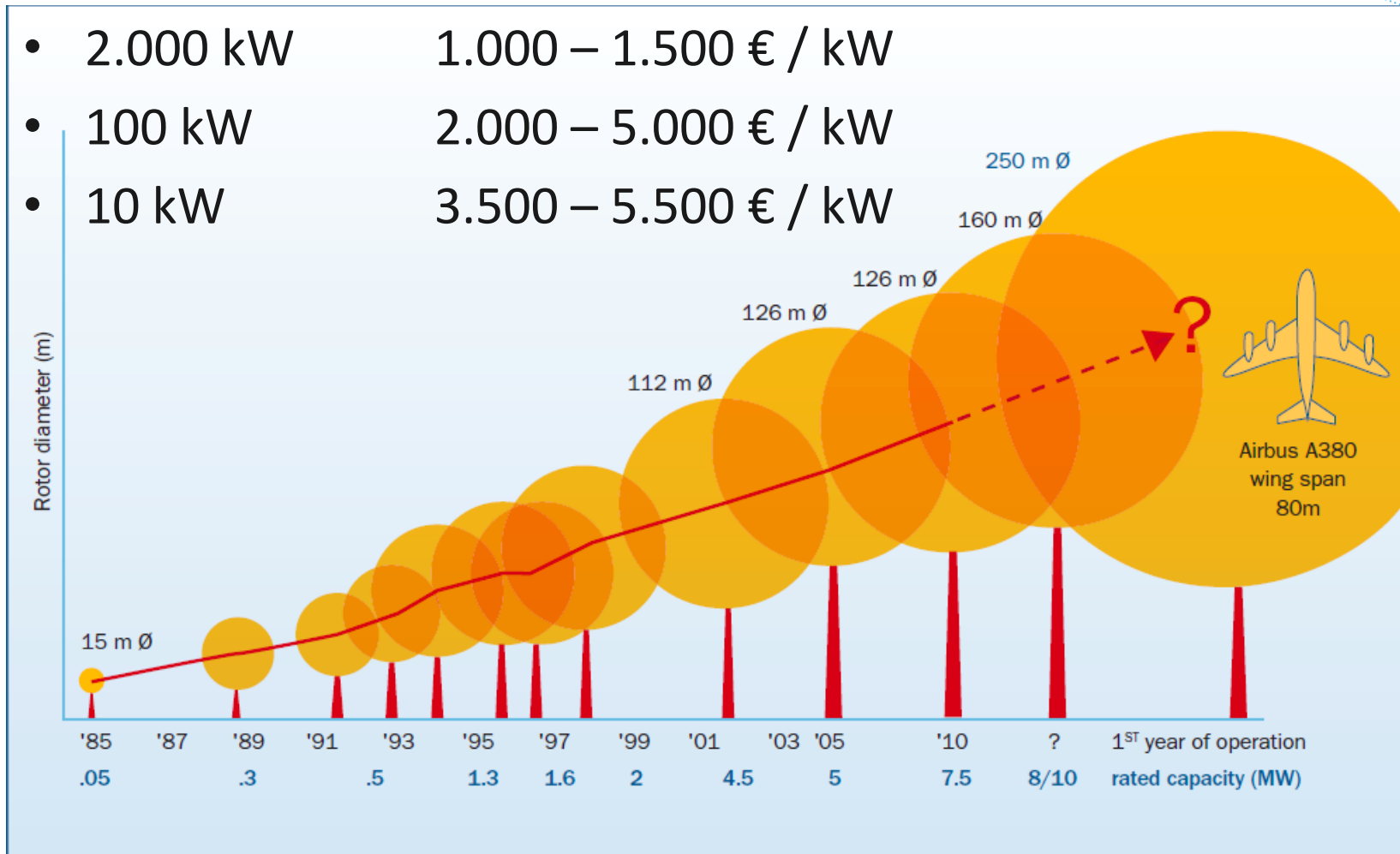


Source: IEA Energy Technology Perspectives 2014

Economy of **size**, wind turbines

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- 2.000 kW 1.000 – 1.500 € / kW
- 100 kW 2.000 – 5.000 € / kW
- 10 kW 3.500 – 5.500 € / kW



Centralized or decentralized ?

Basic rules

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- High economy of scale, **centralized**
 - Wind power
 - Hydro
 - Storage of heat or water
- Low economy of scale, **decentralized**
 - PV solar
 - Storage of electricity in batteries
 - Heat pumps

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[illegible]

Har du också ett smart hem? Tävla med oss!

Går det att leva utan uppkoppling till elnätet? Hans-Olof Nilsson utanför Göteborg har gett sig sjutton på att lyckas. Vintern ska han klara med en bränslecell i källaren och egentillverkad vätgas.

Hans-Olof Nilsson bor i Agnäsberg utanför Göteborg. Till vardags driver han en företaget i vindkraftbranschen. Vid sidan av det ägnar han all ledig tid åt att få det nybyggda huset helt utrustat och färdigt.

På senaste årskningen står det okonstruerad. All el kommer från solcellerna på den stora såderrättande taket och som ligger in i fasaden. Elen som inte behövs för läsket lagras här i två rejäla batterilager som rymmer 144 kWh.

killaren, eller bekräftar det som Hans-Claf Nilsson hävdar. Här är fallt en apparat. Hans-Claf Nilsson slår upp dörrarna till den senaste, en stortjalskip som just levernats från en dansk tillverkare. Där inne döljer sig en elektrohydraulisk apparat som spräddar vatten till vägar och byggar med hjälp av elektrisk energi. En storjalskip som - Viasa Stort till en väg som med på semester. Det här är mitt senaste, säger Hans-Claf Nilsson. Klart är med elektrohydraulisk utformningen på vintern.

Då räcker inte solcellerna och batterierna. Därför ska de kompletteras med växtar som kan tänkas ligga i en tank utanför huset. Växtarna ska tillvaras med jillemikroter.

på runt 15 000 kWh som solen-
larmaker under sommaren. När
solen inte räcker till är det den kal-
la åretsiden förvandlas väg-
gen till både el och värme
(se sida 100).

Leveransen från den svenska biträdesutskottet skrevs av Per-Olof Nilsson, som redan förberett en demokratisk plan för den sk. rik.

Så vitt man kommer jag att köpa väntan jag kan dimensionera systemet. Sådana stödlinjer på väntan, som Per-Olof Nilsson,

para av bli blivt något av en sport. Så kallad väntan stämmer inte på den väntan från väntan och bergs-
 sampan. Huset har extra inledning
 väntan.

När det är kallt förvarmas friskluften genom en 45 meter lång halvort under marken. All luft går via värmefilolator innan den släpps ut.

Är det inte en varnarevadare som ska komma utöver även ut utslagsarmen.

— Det blir inte som en färling med sig själv. Det blir som man går ut igen avskall på komforten?

Alla lampor är så kallat lysdioder och kan programmeras med hjälp av färdighetsanordningssystemet som fungerar som basen för alla. Skärmar sitter lite här och var i alla till exempel i köket, så Hans-Olaf kan ställa till systemet medan han tar en kopp kaffe.

Huset har fler styrbara funktioner. Dessutom finns en sorts av viderrörelsen på taket. Den kan...

- Solen, och blir det frost eller snö, då vänder sig solen i samma uppgångar för att skydda jorden.

han är vill med veten om att det han sparar in på utbildningen inte uppgår det som Westingarna kostar.

– Det är inte konstigt, men det är kul, säger han.

Men det finns en baktanke. På kort sikt ser man gån och fler vill bli elbusskörare. Hoppen har kommit från nytt avnå länd som och kanske jobba med elbussparings och bussar.

MAGNUS ALTHAM, 08-7966 65
ALTHAM@STERNEN.SI

Har du byggt egna lösningar för det smarta hemmet? Dela med dig av dina idéer och var med i tävlingen

"Sveriges smartaste hem".

Det pratas mycket om det smarta, upplagade herramet. Men vi vet att blås Ny Tekniks fönster så är det mer än bara smack. Det skrivs och konstrueras

Vi vet också att det finns ett stort
trevnad för att läsa om hur andra gjort. I
alltid är du träffa Hans-Christof som
i tre år arbetat med att göra sitt eget
litteraturhushåll och observera av en

Men vi letar inte bara efter energi-idén. Allt är välkommet. Det kan vara smarta lösningar för övervakning, uppkoppling, bifit, belysning eller kanske en finurlig bevakningssystem för trädgårdar. Vill du inte ha något avsett?

Mer om tävlingen, regler och hur
avvänder dig hittar du på: rygteknik.

Stata anmälningssdag är den 31 augusti. I höst kommer vi att besöka och rätta om mätning av våra lösningsförmågor. ■

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MARIE ALTMAN, 68-754 65
marie.altman@univie.ac.at

Summary

- NASA:s has instrumental role to:
 - Identify and illustrate the energy dilemma
 - Enable efficient use of renewable power
- Key technologies
 - Electrification
 - Efficiency
 - PV Solar, Wind
- Enabling technologies
 - Power transmission
 - Storage
- Combination of centralized and decentralized solutions

Electricity is likely to remain inexpensive and PV solar will in many areas become the cheapest source...